The All Weather Video

SCIENCE TECHNOLOGY & SOCIETY

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The Science, Technology and Society Series

STS is an international science education movement. It represents the first significant change in the science curriculum in 25 years. The STS concept strives to broaden the scope of science education by integrating into the science program accurate presentations of the nature of science, the nature of technology and the interactions of science and technology with each other and society. This video series provides illustrative examples of the relationships between science, technology and society.

To the Teacher

This video program is intended for use in first year high school (Science 10) as an introduction to a study of weather or as an end of unit activity. The purpose is to show how science and technology, along with human expertise, are applied in meteorology. More specifically, the video program is intended to:

- explain how the sun's energy is the force behind weather
- describe air masses and associated cyclonic weather phenomena
- identify the technology used in forecasting weather
- foster an appreciation of the importance and the complexity of weather forecasting.

This program examines the processes that cause the weather we experience and that are used to predict it. Another thread running through the video is the importance of accurately predicting severe weather. Although climate is touched upon briefly, the main focus of the program is weather and the technological network that is in place to predict it.

Overview of The All Weather Show

The video begins as host Bill Matheson, a professional weather forecaster, looks at

global sized phenomena and briefly mentions some climate types. Then the program focusses on regional phenomena in the cyclonic zone of the Earth, examining and tracking the progression of a cyclone or low pressure system. Finally, local phenomena are discussed, with an emphasis on severe weather, including hurricanes, thunderstorms, and tornadoes.

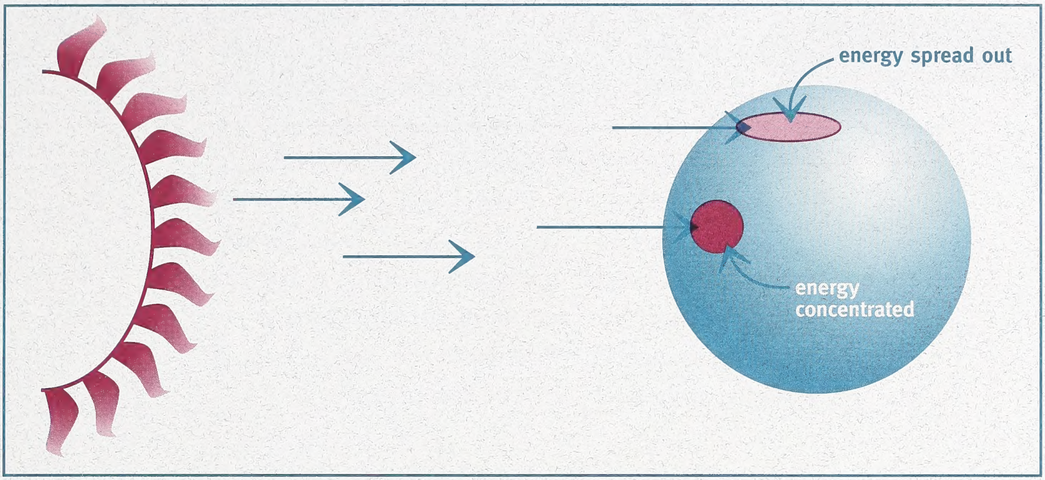
The technology used to predict these phenomena is focussed upon throughout most of the program. The radiosonde, weather satellites, and weather radar (including Doppler radar) are shown, as well as the standard measurement instruments.

Climate

Climate and weather are the combined effects of air pressure, temperature, relative humidity, winds, and precipitation. Day to day changes in these factors are described as **weather**, while **climate** is the average of the weather conditions over several years at some locale.

The sun heats the equator more than the poles. When a temperature gradient is established heat must move from hot to cold. (This is a statement of the second law of thermodynamics.) These two effects taken together set the atmosphere and the oceans into motion. The motion results as heat is transferred from the equatorial to the polar regions of the Earth by convection, producing winds and ocean currents.

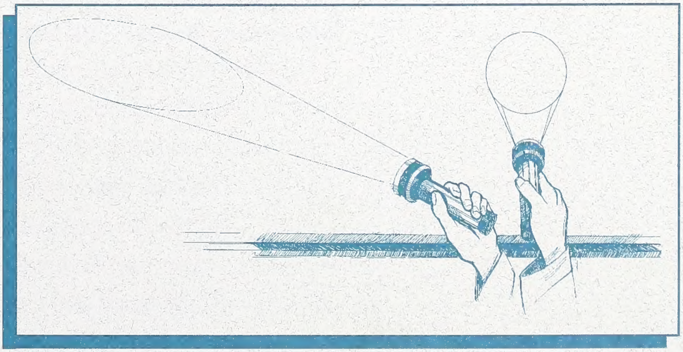
The temperature difference between equator and poles is caused by the angle at which the sun's rays strike the Earth's surface. When a source of radiation hits a surface at an oblique angle its energy is spread out over a greater area than it would cover if it hit the surface at a right angle.



Demonstration

Shine a flashlight onto a blackboard so that the light beam hits the blackboard at a right angle. Draw a chalk line around the circle of light on the blackboard. Repeat this procedure with the flashlight shining at some other angle. (Be sure to keep the flashlight-to-blackboard distance constant. It is easy to show that the second area is larger than the first one.

The same energy is spread out more so each unit square of lit up blackboard gets less radiant energy. When this concept is applied to the Earth it explains why the equatorial regions are the hottest. The Earth's axis is tilted 23.5°, so the place on the Earth that receives the sun's direct rays (known as the ***heat equator****) moves from the Tropic of Cancer on the Summer Solstice to the Tropic of Capricorn on the Winter Solstice. In this program and guide, "equator" refers to the heat equator.*



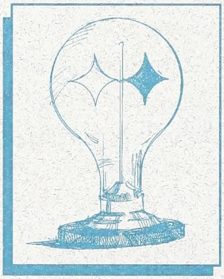
Student Lab

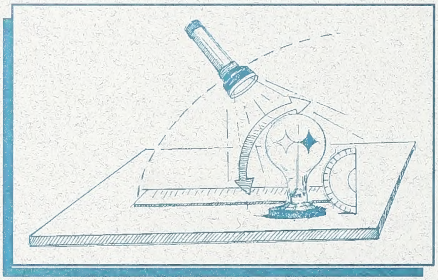
Purpose: *To show the effect of different angles on the strength of radiation.*

Design: *Shine a light on a radiometer at various angles to the plane of the vanes and count how many turns it makes in a certain time period. The distance from the radiometer to the light should be held constant.*

Notes:

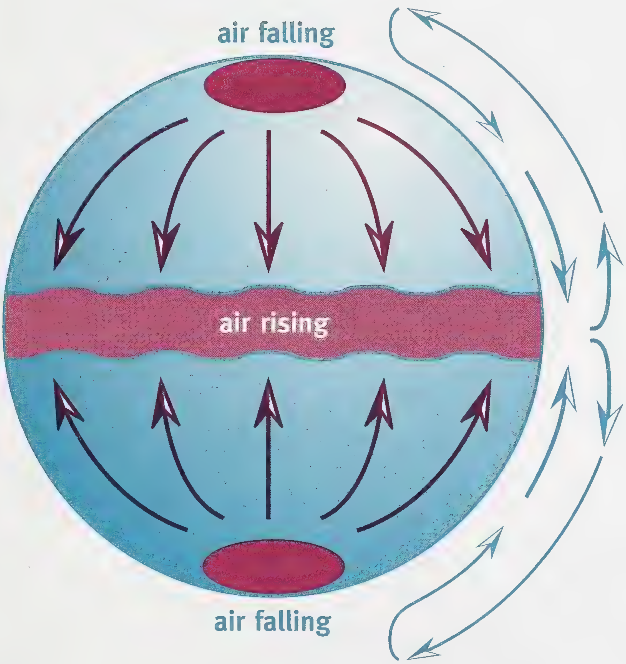
1. *A radiometer is a device that has vanes that spin in proportion to the radiant energy that hits them. They can be obtained through the science supply companies or in most stores that sell science toys. They cost about $15 retail (1993 price) and they have an explanation of how they work printed on the box.*





2. *This lab can be used to work on graphing skills, especially drawing the line of best fit. The data points usually have some scatter to them but the overall trend is that smaller angles (light beam to the surface of the vanes) produce a slower rate of turn of the vanes (90° perpendicular to the plane of the vanes is the "equator" and 0° parallel to the plane of the vanes is the "north pole").*

The experiment, applied to world climate, shows that **latitude** is an important climatic factor. It may very well be the most important climatic factor of all. If latitude were the only factor affecting climate the Earth's atmosphere might move in the way this simple model suggests.



This model predicts that a belt of calm air should exist at the equator (the air is only rising), and that regions of calm air should also exist at the poles (the air is falling). Between these locations the winds should blow from the poles to the equator.

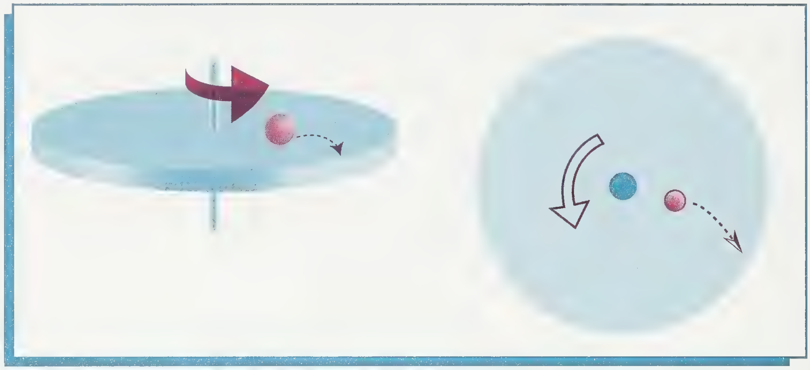
In fact, the winds do no such thing! The model must be missing some other important factors.

The missing factor in the previous model is the **Earth's rotation**. Imagine a rotating platform (like a merry-go-round). An object travelling on it experiences forces that tend to push the object off the rotating platform. The "forces" seem do two things:

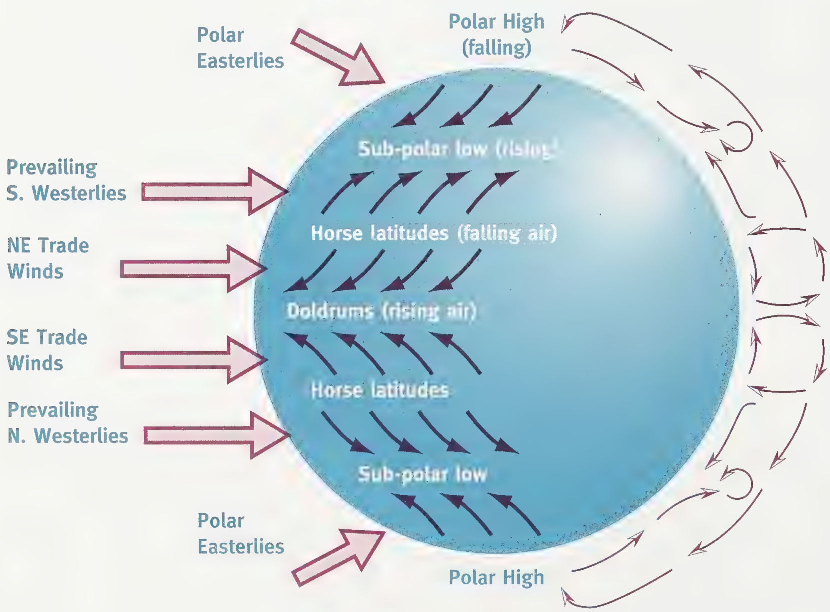
1. Push the object away from the centre of rotation (the **centrifugal force**).
2. Deflect the object sideways as it moves outward (the **coriolis force**).

An object on a rotating surface will move in a curved trajectory

outwards from the centre of the rotation *relative to the surface.*



The coriolis force, when applied to the winds on the Earth, a rotating surface, deflect to the right in the northern hemisphere and to the left in the southern hemisphere. The rate of rotation determines how much they deflect. Adding the coriolis force to the model produces a very different picture.



This model is about sixty years old and is found in all the textbooks. It comes much closer to what is observed but has shortcomings of its own. The predicted windy and calm belts do not appear except over water. The trade winds do appear where predicted except in the Indian Ocean. This model might work on a planet completely covered by water but the presence of land masses must also be included in any serious attempt to model world climate.

Jupiter and Saturn are fluid covered planets and their surfaces do display the banded structures predicted by this model. They have more convection cells because they rotate much faster than the Earth does and the coriolis force is greater.

By the 1970's a great deal had been discovered about the upper levels of the troposphere (the bottom layer of the atmosphere where the weather occurs). Even today the workings of this part of the atmosphere are not well understood but they do play an important role in the Earth's climates.

Layers of the Atmosphere

Standard diagram in any earth science text.

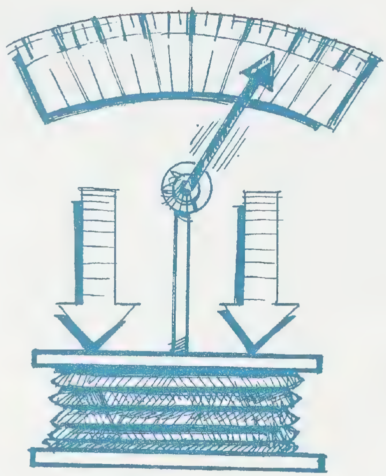
The **jet streams** are tubes of extremely fast winds that race around above the middle third of the planet in a zigzag fashion. When they move toward the equator they also lose altitude and when they move pole-ward they gain altitude. They transfer heat from tropical to arctic areas and influence the direction of surface weather beneath them.

The air above us has weight and exerts a force on everything on the Earth. The pressure (force per unit area) associated with this force is the **air pressure** or **atmospheric pressure**. Its value is dependent upon local conditions (such as altitude). Standard air pressure is equal to:

- 101.3 kPa
- 76mm of mercury (29.92 inches of mercury)
- 14.7 psi (pounds per square inch)

Air pressure is measured with a **barometer**. The type found in most small weather stations is an **aneroid** barometer.

Aneroid Barometer

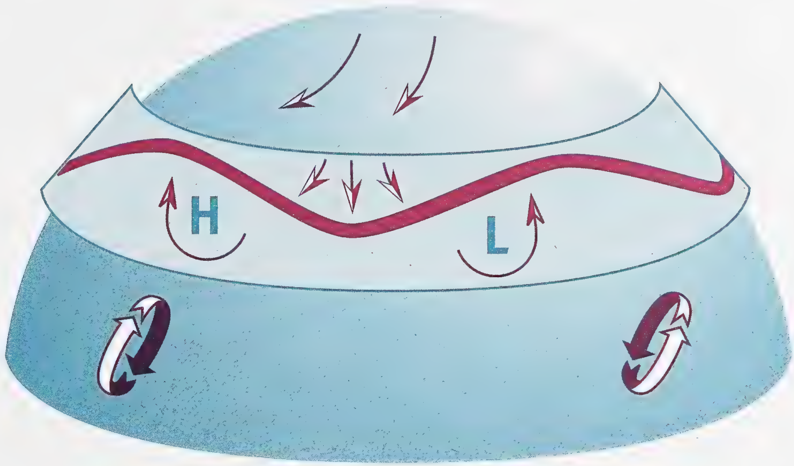


High pressure squeezes bellows in and pulls needle to "HIGH."

Low pressure lets bellows out and pushes needle to "LOW."

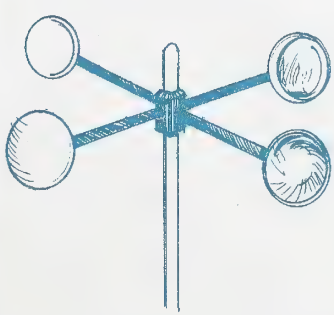
When air rises its pressure drops, producing a **low pressure centre**. When air descends its pressure increases, producing a **high pressure centre**. Jet streams therefore create highs as they move toward the equator and lows as they move pole-ward.

Here is a model that includes the jet streams.



This model comes even closer to the actual global wind patterns.

Wind speed is measured with an **anemometer**; wind direction with a **weather** *vane*.

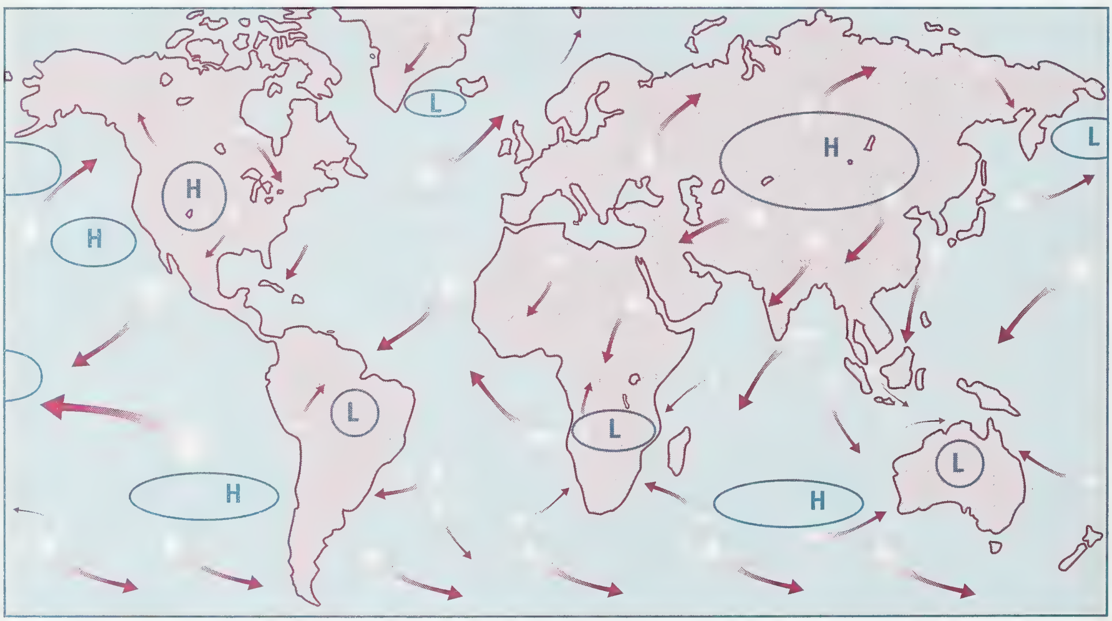


A spinning anemometer turns a cable hooked to a scale below.

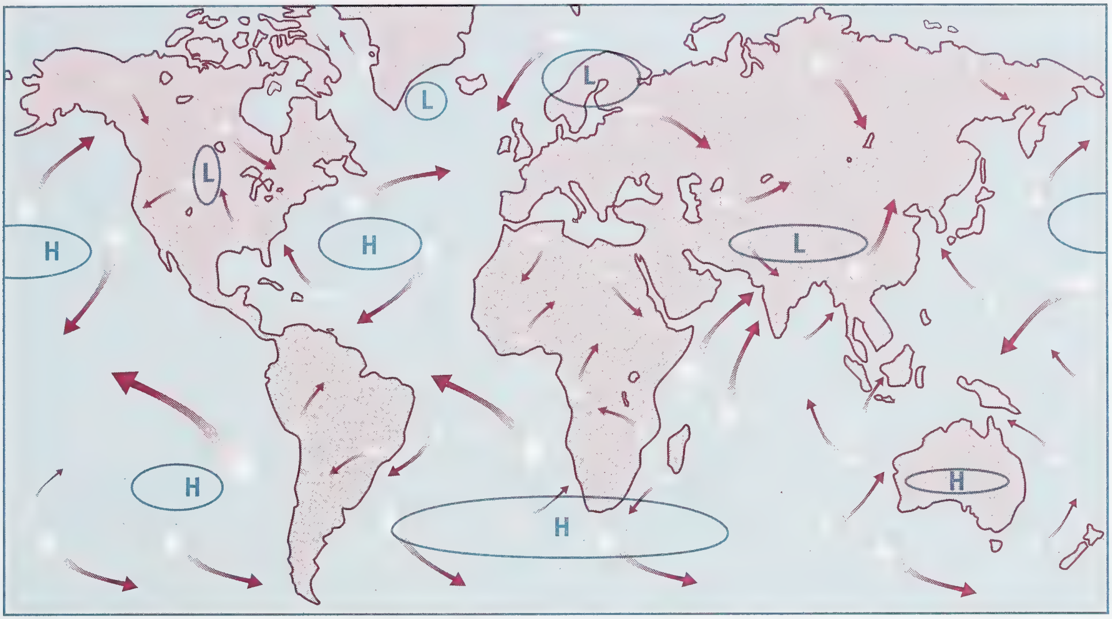
Student Project

Look in an atlas and find the actual pattern of global winds. Compare these to those predicted by the second and third models. Discuss which model works best and where the models break down.

Here are the maps of where the Earth's winds actually do blow (on average). The reason for two maps is, again, that the tilt of the Earth's axis moves the heat equator throughout the year.



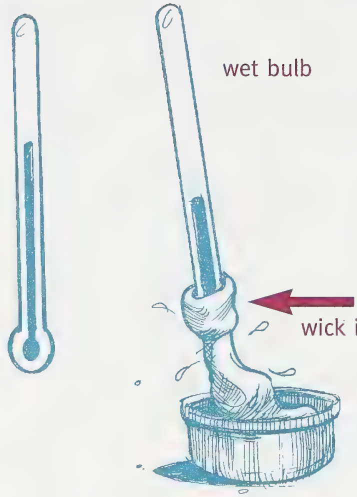
Earth -- Pressure and Winds January



Earth — Pressure and Winds
July

The atmosphere is a chaotic system and the winds shown in these maps don't show the smaller scale movements that are always present as well. Large "blobs" of air covering thousands of square kilometres of surface sometimes stop for days or weeks. These are called *air masses* and they gradually take on the temperature and humidity characteristics of the Earth below them. Air masses are named according to the location where they were formed. **Continental** air masses form over land and **maritime** air masses form over water. In addition, they are classified as **tropical**, **arctic**, or **polar**.

Nearness to and direction from large bodies of water is another of the major factors that determines climate. If a maritime air mass were to move inland it would probably cause that land to have a lot of precipitation. A continental air mass brings drier conditions.



Warm air can hold more moisture than cold air can. If the actual amount of water in the air is compared to the maximum amount of water the air can hold at that particular temperature the result is the **relative humidity** (or **RH**). The RH is expressed as a percent.

$$RH = \frac{\text{actual amount of moisture}}{\text{maximum amount of moisture}} \times 100$$

RH is measured with a **hygrometer**. One kind of **hygrometer**, a **sling psychrometer,** uses the rate of evaporation to determine the RH.

The lower the RH, the more evaporation that occurs on the wet bulb and its temperature is therefore lower.

A chart of dry bulb temperature and wet bulb temperature is read to obtain the RH.

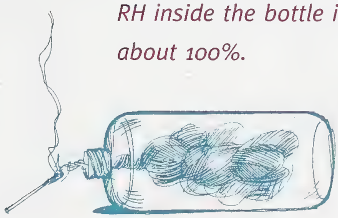
When air rises it expands and cools. As it cools its RH increases. This occurs because the actual moisture content of the air stays constant while the maximum amount that can be held drops. The fraction's value increases. If air continues to

rise, eventually its RH will reach 100% and the water vapour will condense into water droplets or sublime into ice crystals. In either case clouds will form. The temperature at which the RH reaches 100% is called the **dew point**.

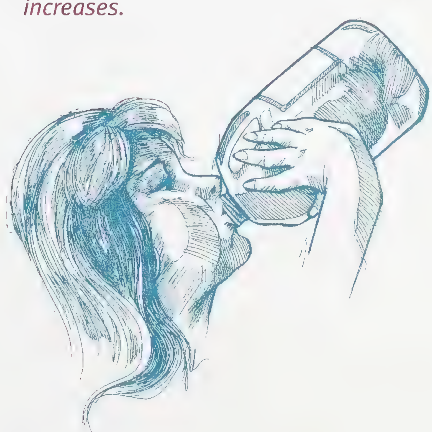
The opposite of this occurs when air falls. It compresses and warms up. The RH falls and any clouds are likely to disappear as the water evaporates.

Demonstration

1. *Partly fill a plastic pop bottle with water, swish it around and empty it. The RH inside the bottle is now about 100%.*



2. *Light a match, hold it near the bottle mouth and blow it out. Direct the smoke into the bottle. This provides condensation nuclei for the water molecules to condense on.*
3. *Blow into the bottle as if you were trying to blow it up like a balloon and suddenly release your mouth. A cloud will appear in the bottle! It looks like a tiny bit of fog in the bottle. Fog is, in fact, a cloud at ground level.*
4. *Blow again. The cloud disappears as the pressure increases.*



High and low pressure centres are major climatic factors. A climate dominated by low pressure will be cloudy and wet. The world's rain forests are examples of such climates. Climates dominated by high pressure will be sunny and dry. The world's great deserts are examples of these climates.

Mountains cause this effect as well, although on a smaller scale. As air rises to go over a mountain it loses moisture. Once over the top, the air descends and heats up. Places on the windward side of a mountain will have wet climates while those on the leeward side will be desert-like. This is called the **rain shadow effect**. Chinooks are very warm and dry winds that form as air falls down the eastern slopes of the Rocky Mountains in southern Alberta. **Nearness to mountains** is another climatic effect, although somewhat localised.

The higher up you go, the colder it is. This is because the Earth's surface is heated by the ground. **Altitude** also influences climate.

Lastly, the **ground cover** can influence climate. This is the way in which climate was first changed by people in a drastic way. Two thousand years ago, Carthage, now North Africa, was a lush farming area. The Romans sowed salt into the soil of the enemy city and the area is still a desert today. Once the plants were gone there was nothing to prevent the desert from claiming the area.

Ocean currents

The water of the oceans is also moving in convective loops called ocean currents. Warm water from the tropics loops pole-ward carrying enormous quantities of heat with it. The routes of these currents depend upon the positions of the continents, so there is a tectonic influence as well.

Earth — World Ocean Currents
January

There are also ocean currents that circulate deep below the surface. One such current, called the Atlantic conveyer, circulates over much of the world. It is powered by the formation of streams of moving deep water south of Greenland. As water flows northward along the Gulf Stream it cools, contracts and becomes more dense. Its salinity increases as evaporation occurs, also increasing its density. The density reaches a point where the water sinks through the less dense layers of water below, and the cold, salty water returns southward near the ocean bottom.

The Gulf Stream carries warm water much farther north than occurs anywhere else on Earth. As a result Europe is about 8°C warmer than it should be!

The flow of warm water from the western to the eastern Pacific Ocean is the Equatorial Counter-current. It varies in strength in a semi-regular fashion. When it is particularly strong the warm water it carries overrides the cold water that sits off the coast of Peru. This effect is *El Nino* and when it occurs a strong ridge of high pressure sets up over western British Columbia, which sends the jet stream far to the north. The weather in the northern hemisphere becomes unpredictable or abnormal when El Nino is active.

Earth -- World Ocean Currents July

Student Project

1. *Have the students look at the maps of global winds and predict climate for different regions.*

   - *What places always have low pressure? high pressure?*
   - *What places have low pressure for half of the year?*
   - *Look for places where the spiralling wind patterns around lows and highs would bring maritime air to a location (or continental air).*
   - *Where should tropical rain forests be located?*
   - *Where should deserts be located? (Don't forget the mountains.)*
   - *Should Vancouver or Halifax be wetter? Why?*
   - *Should Edmonton or London, England, be hotter? Why?*

   These are just a few possible questions. Many others are possible.

2. *Have the class prepare climate graphs of cities all around the world, including latitude, longitude and altitude for each. Students could each produce one or two. In groups, students could control climate factors and compare similar locations.*

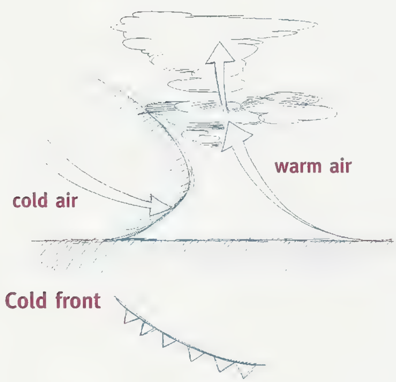
   - *Do all places with the same latitude have similar climates?*
   - *Do all places with similar latitude and altitude have similar climates?*

   Alternatively, have students group cities into those with similar climate types and look for reasons why they might be similar.

   Look for exceptions to the rules and try to find the reason(s) for the exceptions. Reykjavik, Iceland comes to mind.

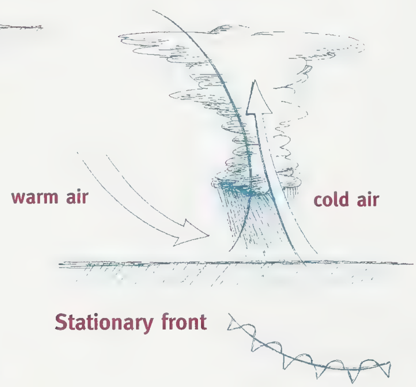
Weather

Weather is more variable than climate but it is determined in the same ways. When air masses move around they contact and push on each other. Two air masses that have different characteristics do not mix easily. It may take days or weeks for a moving air mass to mix with its new surroundings. When air masses touch, the boundary between them is called a **front**. Fronts are classified as:

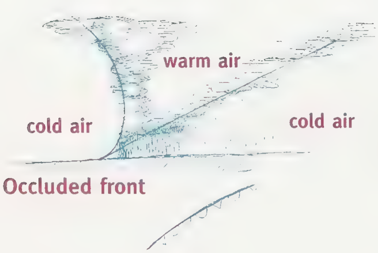


Cold front

Warm front



Stationary front

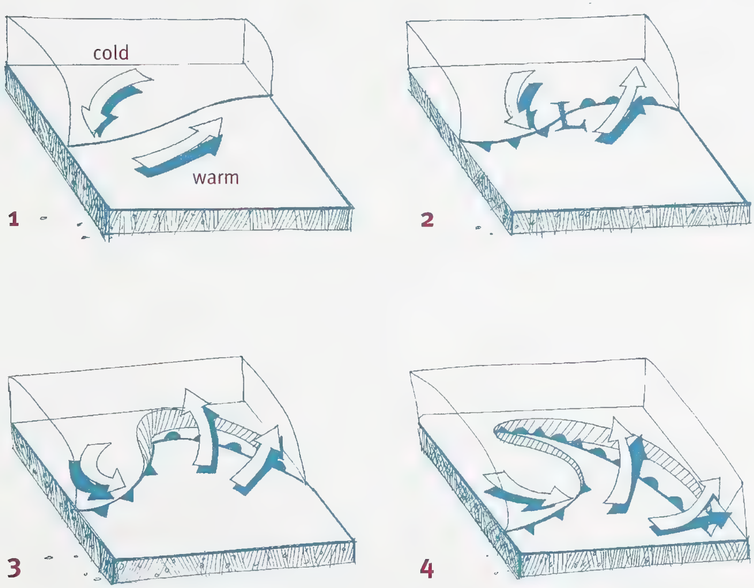


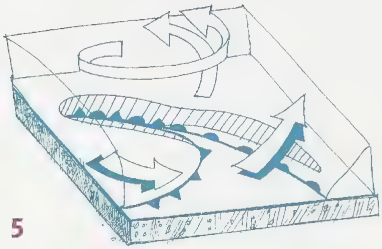
Occluded front

Upper front or trowal
Trough of warm air aloft

When fronts are moving through a locale they tend to cause some kind of precipitation and winds. Much of the weather of Canada and the U.S. is caused by fronts associated with **cyclones**. A cyclone is a low pressure centre and its attendant winds. (It is not a tornado.)

When air rises to produce a low pressure centre a partial vacuum is produced. Air nearby rushes in to replace the risen air (winds). These winds spiral counterclockwise in toward the pressure centre as a result of the coriolis force. Cooler air advances southward on one side of the centre while warm air advances northward on the other side. Here is the progression of a typical cyclone.





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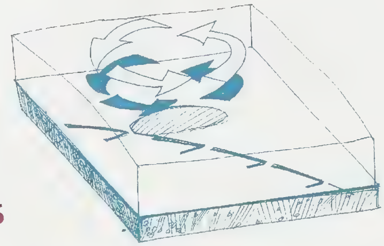

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Precipitation often occurs when no fronts are in a vicinity. Waves of cold air left over from other systems can be moving across the sky at high altitude, influenced by the jet streams. If warm air rises and hits the cold air aloft large clouds associated with storms result. After a bout of cold temperatures, a location often experiences afternoon showers on warm sunny days. This happens because the air aloft is so cold that the updrafts caused by heating air produce extra tall clouds. Air with such a large temperature gradient is termed **unstable**.

Student Lab

Cut out the weather map from the local newspaper each day for a period of about one week. Relate the details on the maps to the weather experienced during the same period of time.

Choosing a time of changeable weather will probably include cyclonic activity. Try to identify a cyclone in the set of maps.

Severe Weather

Complex convection at a smaller scale occurs within the

overall convection of a low pressure system. Near a cold front the vertical speed of the rising air is extreme. This strong vertical convection produces clouds that start at 2000 metres and grow from 10 to 16 kilometres high! These are **cumulonimbus** clouds, which are responsible for such things as heavy rain, hail, thunderstorms, tornadoes and hurricanes.

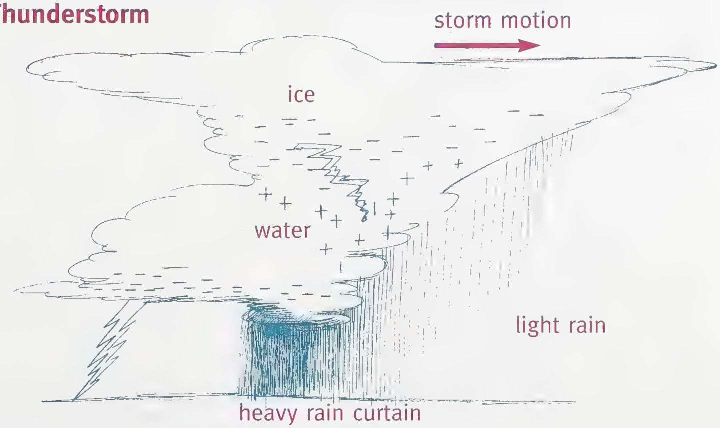
These clouds serve another purpose or two as well. Water vapour contains a huge amount of latent heat (2268 J/g). This heat is carried to the top parts of the troposphere and released there when the water vapour condenses. These clouds act as immense heat pumps!

With over 100 lightning strikes per second, the Earth acts like a huge electric capacitor that is constantly charging and discharging. The lightning helps to fix nitrogen into the soil, producing nutrition for plants.

Thunderstorms

Ice crystals and water droplets build up opposite electric charges when they rub together. Large positive and negative charges collect in various places in the cloud.

Thunderstorm



Thunderstorms occur when giant sparks of electricity move from one part of the cloud to another, from one cloud to another, or from a cloud to the ground as these discharge. Lightning's temperature is 40,000°C! It heats the air around it so much that the air expands away from the lightning at supersonic speed. This results in a sonic boom called thunder.

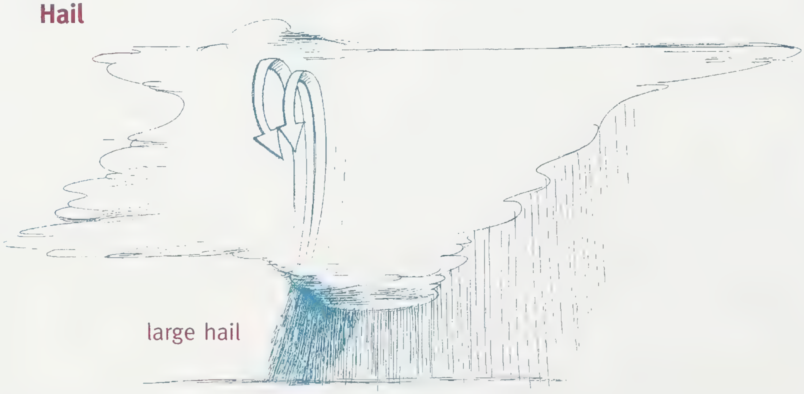
Hail

Hail occurs if the updrafts in the cloud are strong enough to hold very heavy, ice covered raindrops in the cloud and toss them around. They get layers of water and ice crystals added to them until they are heavy enough to fall. The largest recorded hailstone was the size of a grapefruit!

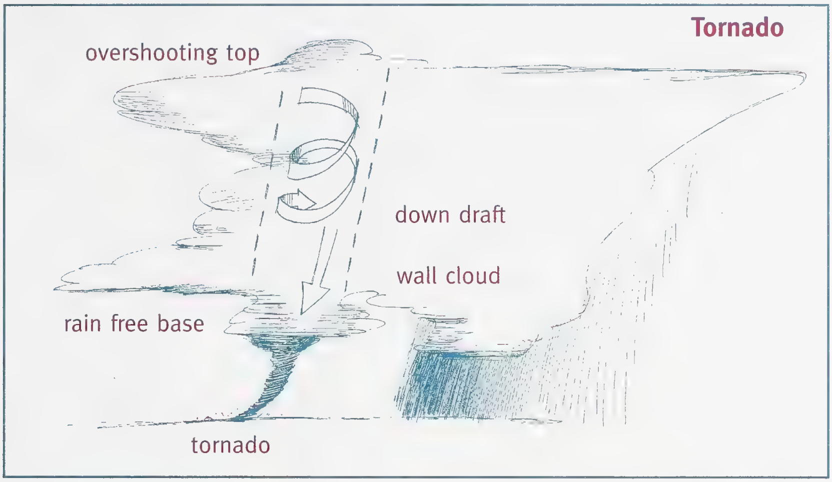
Tornadoes

Tornadoes produce the strongest winds of any type of storm. It takes a large cumulonimbus cloud with well organised downdrafts in it to produce a tornado. The storm's updrafts and downdrafts combine in a still poorly understood way to produce a rotating column within the cloud. This produces a rotating wall of cloud which can tighten and push down toward the

Hail

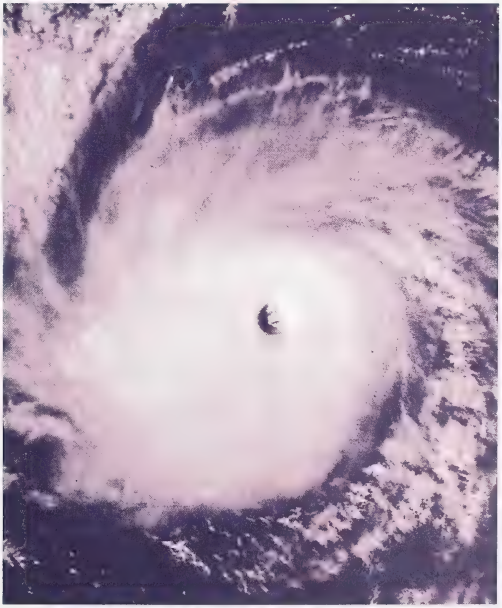


ground (the **funnel**). When the funnel reaches the ground it is called a tornado. Winds of up to 500 km/h can be produced.

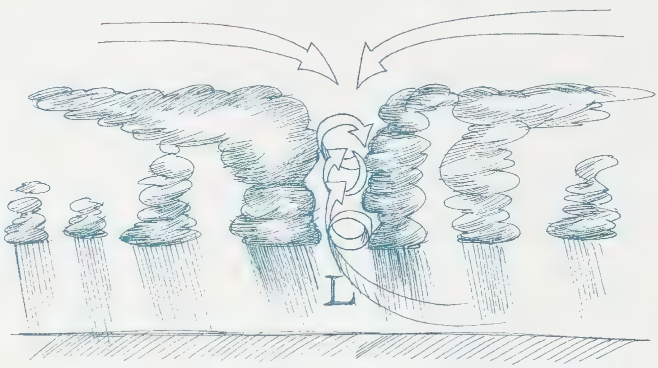


Hurricanes

Hurricanes are the largest storms on Earth. They are organised cyclones hundreds of kilometres in diameter that contain bands of rainstorms that increase in intensity toward the centre of the storm. The low pressure centre, the **eye**, begins the storm by elevating warm moist air. Hurricanes can only form over water that is at least 26°C. The temperature of the water ensures a great deal of



Cross section of a Hurricane

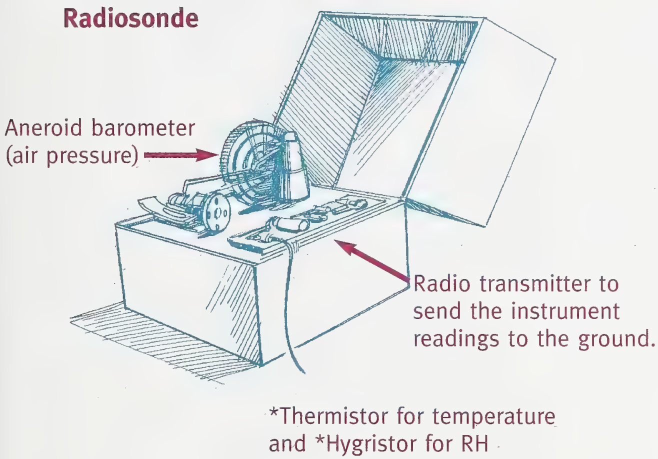


evaporation and when this huge amount of water vapour condenses in the upper parts of the storm the released latent heat provides the energy needed to build the storm's intensity. Hurricanes live until they move over land or over colder water—often for weeks. The wall at the centre is a connected set of cumulonimbus clouds with heavy rains and winds of up to 150km/h. Under the eye of the storm it is sunny and dead calm—with the prospect of renewed violence at the other side of the wall!

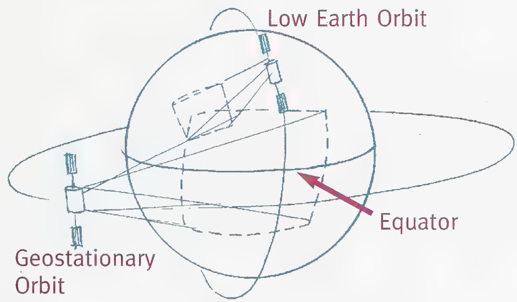
Meteorologists use peoples' names to identify hurricanes. Boys' and girls' names are assigned to the storms in alphabetical order. (The first storm of the year will have an "A" name and so on.) The list of the names to be used is published a year in advance.

A great deal has been learned about weather in the last few decades. **Radiosondes** are sent up in weather balloons to measure temperature, air pressure, relative humidity, wind speed and wind direction twice a day, every day, from 300 locations. Meteorologists track these instruments with radio equipment and add their data to the surface data in order to make the weather forecasts.

When radiosondes fall back to Earth they are not reused. Most crash land and are destroyed upon impact. The ones launched in populated areas have parachutes to protect the people below.



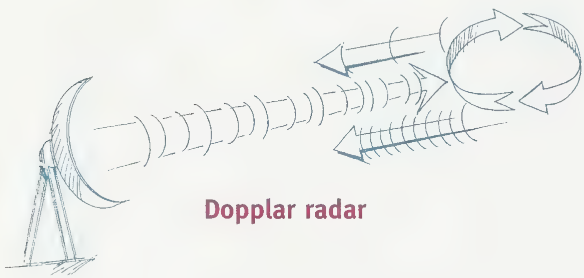
Weather satellites take pictures of the atmosphere from above and show large and medium scale systems that might be missed otherwise. Some orbit high enough above the Earth that they take 24 hours to complete one trip around it and therefore stay above one place all the time. Such a satellite it said to be **geostationary**. Geostationary satellites are placed over the equator and can see almost half the Earth at a time. Other satellites get around in about 90 minutes in lower orbits. These satellites see smaller areas but can take more detailed pictures.



Another new technology being used is **radar** (radio, detecting and ranging). Radio waves will bounce off large rain drops in clouds, so a radar beam can detect those clouds that might harbour severe rain. **Doppler radar** is the latest piece of equipment in the meteorologist's arsenal. When radar beams reflect off raindrops that are moving

*Devices that convert what they sense into variable voltages

towards or away from them the beam frequency changes. The frequency goes up if the raindrops are approaching the incident beam and it goes down if they are receding from the beam. This shows as a colour shift on the screen. Spiralling winds in a cloud, the precursors of tornadoes, are detected with Doppler radar.



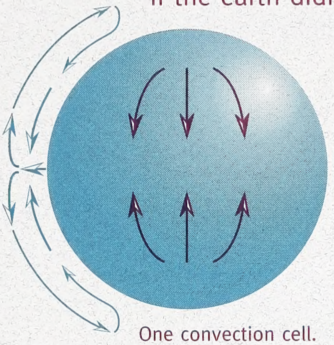
Dopplar radar

If a cloud shows both approaching and receding raindrops (and therefore winds), it has spiralling winds in it and may form a tornado.

Lastly, a word about **chaos theory**. Edward Lorence, a meteorologist, discovered that the weather was sufficiently complex that its behaviour couldn't be predicted beyond a certain time. Tiny changes in atmospheric conditions at one time cause huge differences in conditions later on. Meteorologists can predict conditions 24 hours in advance accurately most of the time. The five day forcast is still just a guess, and may always be!

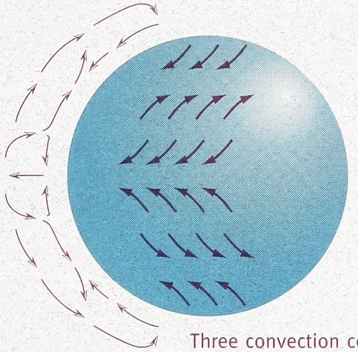
Global Climate

If the earth didn't rotate



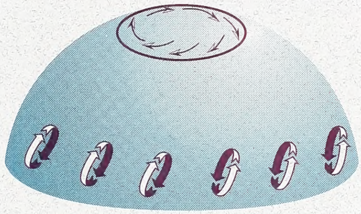
One convection cell.
Surface winds would blow from the poles to the equator. This doesn't happen.

Rotate the Earth

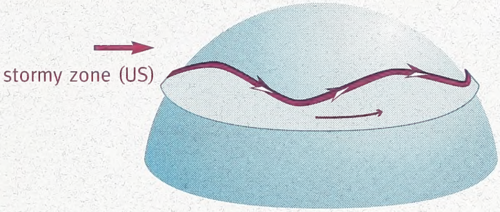


Three convection cells. Wind directions depend upon latitude. This is the model seen in most texts. It has been around for 60 years or so. It's not bad but......

1. Polar Easterlies seep out from the poles.

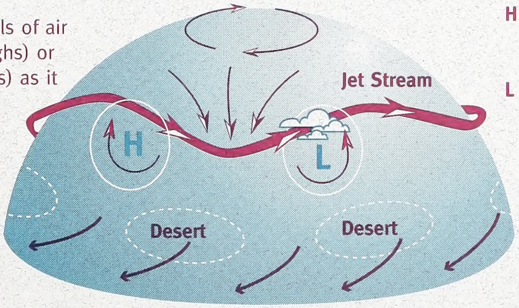


2. Trade Winds are part of a convection cell near the equator.



3. The Jet Streams zig-zag around the Earth's "stormy zone", transferring heat from the equatorial zones to the poles.

Jet stream causes swirls of air that are clockwise (highs) or counterclockwise (lows) as it rises and falls.



H – high pressure area
– clear, calm

L – low pressure area
– cloudy, windy, stormy

Doldrums – Band of Low Pressure

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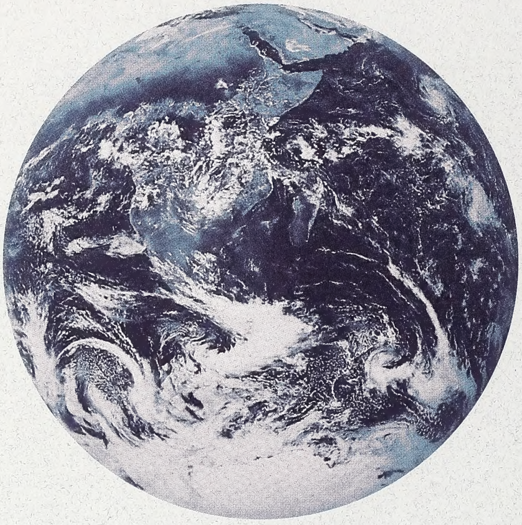

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